

Tracking Urban Human Activity from Mobile Phone Calling Patterns

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ABSTRACT

Human activity in big cities follows daily rhythms by being entrained to different exogenous clocks. Here we exploit the large-scale data analysis techniques to study the calling activity in highly populated cities to infer the dynamics of urban daily rhythms. From the calling patterns of one million users spread over different cities but lying inside the same time-zone, we show that the onset and termination of the calling activity synchronizes with the east-west progression of the sun. We also find that the onset and termination of the calling activity of users follows a yearly dynamics, varying across seasons, and that its timings are entrained to the solar midnight. Furthermore, we show that the average mid-sleep time of people living in the urban areas depends on the age and gender of each cohort as a result of biological and social factors.

INTRODUCTION

The daily activity of people varies from place to place, date to date, and hour to hour as a result of biological, societal, economical, and environmental factors influencing the timing of their activity. In modern societies, daily activities are entrained by different circadian rhythms, each one following a different clock and timing. One of these rhythms is marked by events related to the period and timing of sunlight, and they, in turn, are subjected to seasonal changes due to the yearly movement of Earth around the Sun. Another rhythm follows a local, civil time (UTM), where social and economical clocks fix the specific times for certain activities. At population level, the overall activity of humans, even in bigger urban areas, follows a characteristic and regular pattern, with high activity periods during the morning and evening, and low activity periods during the night or times of rest. The study and understanding of the length and timings of the activity periods, specially in urban areas, has important consequences for human health, economy and wealth, power consumption, and public transportation efficiency.

The human sleep wake cycle (SWC) and its dynamics in particular has been studied in recent years, trying to understand and identify what are the processes and pacemakers governing it [1]. In general, the current research on the human SWC has focused on experiments of small groups

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under controlled situations [2, 3], and on questionnaire studies [4, 5]. The subjectivity introduced by these approaches makes it difficult to draw general conclusions about the dynamics of the SWC, especially when determining which of the possible exogenous clocks it follows. However, recently the presence of new digital communication technologies as well as the accessibility to large-scale techno-social datasets (‘Big data’) have allowed the study of human behaviour from diverse perspectives by the application of reality (data) mining techniques. In particular, mobile phone call detail records (CDRs) have been analyzed to study social networks [6–9], sociobiology [10, 11], and intrinsic mental health [12], social behaviour of cities [13, 14], as well as sleep patterns [15–18]. Hence, over the past decade or so, the existence and accessibility of these large population-level datasets, has allowed scientists to study intrinsic human behavioural and socio-evolutionary patterns in an unprecedented way.

In this study, we apply reality mining techniques to users’ call records of a mobile phone communication network, to study the dynamics of the users’ activity pattern by focusing on its inactivity time, i.e. when almost no calls are made. Users of the mobile phone network have specific time intervals when their calling activity ceases, and it can be expected that SWC is bounded inside this inactivity time. We observe that the daily calling activity time displays an interesting dynamics along the year through seasons and along different geographical zones. By studying these patterns we can gain insight into the human activity and the sleep wake cycle, in particular. Interestingly, the calling activity pattern changes with the day of the year and it is found to depend also on the geographical location, i.e. latitude and longitude of the mobile phone user. From the circadian clocks involved in the daily rhythms of human societies, only those entrained to solar-based events depend also on the geographical location and day of the year. In this study we address the questions of how and to what extent the timings of urban human activities depend on the sun-time related quantities, which circadian clock is pacemaking this dynamics, and how the resting period times of people with different characteristics entrain to the same circadian rhythm.

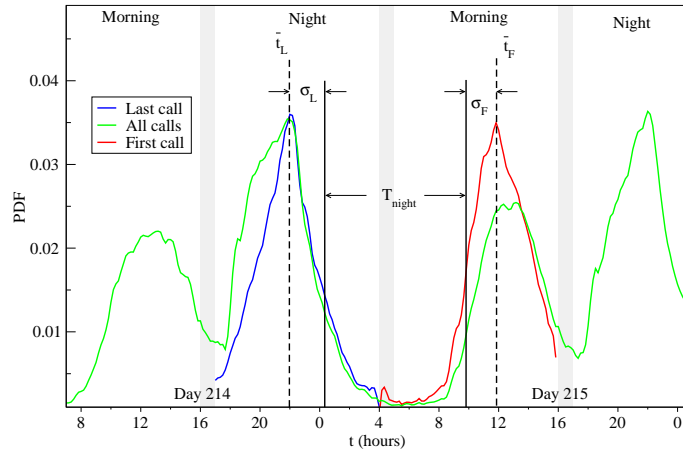


FIG. 1. **Probability distribution for finding a call at time t , for a particular in 2007.** (green) Distribution when all the calls are included. (red) Distribution when only the last call at night is included (between 5pm and 4am next day). (blue) Distribution when only the first call of the day is included (between 5am and 4pm). The distribution of the last and first calls are sharper and have well-defined maxima.

RESULTS

Using an anonymized dataset containing details of mobile phone communication of subscribers of a particular operator in a European country described in detail in the Methods section, we investigate the calling activity of the urban population living in cities as a function of time of the day for all the dates during the year. This we do by calculating for each city the probability distribution $P_{all}(t, d)$ for finding an outgoing call at time t of a day $d = (1, \dots, 365)$ of the year. For all the cities, a region of almost null activity can be found around 4:00 am. Using this natural bound to split the calling activity from one day to another, we define a ‘day’ starting from 4:00am of a calendar day and running to 3:59am of the next calendar day.

In Fig. 1 we show $P_{all}(t, d)$ (green curve) during the days $d=214 - 215$ (early August) for a city with over a half a million inhabitants. The distribution $P_{all}(t, d)$ has two high activity peaks with the first corresponding to the morning calls, peaking around noon, and the second related to the evening calls, peaking around 8:00 pm. This bimodal pattern is present in every day across the year and all the cities included in this study. The high activity peaks are delimited by two periods of low activity, one centered around 4:00 pm related to the time after lunch, and the second one in the middle of the night, around 4:00 am within the sleeping period.

Urban activity synchronization with East-West Sun progression

The mean time for the first call t_F and for the last call t_L of people in a city can be influenced by environmental, social, and economic factors, and their possible daily value could be distributed completely at random. However, we find that during the year and at different latitudes, despite the different factors influencing the shape of the distribution P_{all} , the onset and termination of calling activity follow a consistent pattern, and this characteristic behaviour allows us to compare the calling activity pattern of cities lying at different latitudes. If the onset or termination of the urban calling activity is socially driven, with fixed times for specific activities (like office working hours from 9:00am to 6:00pm), one could expect that cities lying in the same time zone and at the same latitudes, show similar timings. However, we find that the onset and termination of calling activity synchronize with the East-West sun progression, in such a way that cities lying in western locations start (and terminate) their calling activity after cities at eastern locations, with a delay difference corresponding to the time difference between their local meridians. In Figs. 2A-B we show t_L and t_F for 5 different cities lying inside a latitudinal band centered at $42^\circ\text{N} \pm 40'$. The region including the 5 cities spans over a longitudinal angle of 10.8° , and by taking one of the cities as a reference, other cities are located at -7.8° , -4.7° , -3.7° , and 3.0° from the reference city marked here with 0.0° . Then we compare the actual distributions P_L and P_F of the time of the last call and of the first call, respectively, for the 5 cities in the given latitudinal band, and find that P_L and P_F for western cities seem shifted to later times. However, when a time shift is introduced to each distribution, corresponding exactly with the time difference between the local meridian of each city and the reference city, the distributions visibly collapse into each other, as can be seen in Figs. 1C-D. In this case, the time shifts are +31.2, +18.8, +14.8, and -12 minutes for the cities located at -7.7° , -4.7° , -3.7° , and $+3^\circ$ from the reference city at 0° , respectively.

The distribution collapse shown in Figs. 2 is obtained by introducing a time shift corresponding to the sun transit differences between cities. In order to quantify the exact delay between the distributions, we calculate the required time shift that should be introduced between the calling distributions to minimize the Kullback-Leibler divergence D_{KL} between them (see Methods section). This measure is indicative of the similarity between the distributions, and is minimized when

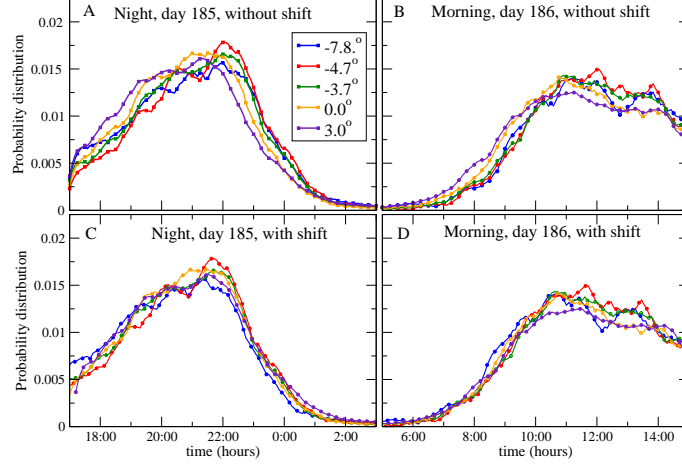


FIG. 2. Temporal shift of the onset and termination times of the calling activity along geographical longitude. Probability distributions of the time of the last call $P_L(t, d)$ and that of the first call $P_F(t, d)$ for 5 different cities lying at the same latitude but at different relative longitudes from a reference point located at the second city from east to west within the band for two different days during the year. The relative longitudes of the cities are -7.8° , -4.7° , -3.7° , 0° , and 3° . Probability distribution for (A) the time of the last call, and (B) the time of first call. (Bottom) Probability distributions for (A) the time of the last call, and (B) the time of first call, shifted by a time corresponding to the difference between their local sun transit times (31.2, 18.8, 14.8, and -12 minutes for the cities located at -7.8° , -4.7° , -3.7° , and 3° from the reference city, respectively). The collapse of the distributions onto the reference city's distribution is evident when the longitudinal time shift is added. This collapse implies that these 5 cities begin (or cease) their calling activity in a synchronized way, with a temporal phase corresponding to the difference between their sun transit times.

they are identical. Also, we have extended the analysis to include data of 30 cities, each one lying in one of four latitudinal bands centered at 37°N (10 cities), 39.5°N (5 cities), 41.5°N (7 cities), and 42.5°N (8 cities), and calculate the average time shift for all the days of the week, averaged over all the 52 weeks of the year 2007. For each band, one city in the middle of the band is chosen as the reference city. The results are shown in Fig. 3, and it can be seen that the temporal shift that minimizes the divergence corresponds to the delay between their local sun transit times, with a stronger effect for the calling activity termination (P_L). Applying this analysis to cities lying in the four different latitudinal bands, shows that these results are consistent and they follow some general behaviour of the population living in the cities. This result also implies that the termination (last call of the day) and onset (first call of the next day) of the calling activities in cities at the same latitude follow an external clock marked by solar events, and the time difference when these solar events happening in two different cities is reflected in the timings of their calling activity.

Entrainment of urban calling activity with sun-based pacemakers

We have shown that the cities located at the same latitude but at different longitudes have periods of low calling activity with different onset and termination times (Figs. 2 and 3). This shift coincides with the difference between their local sun transit times, i.e. when the sun crosses

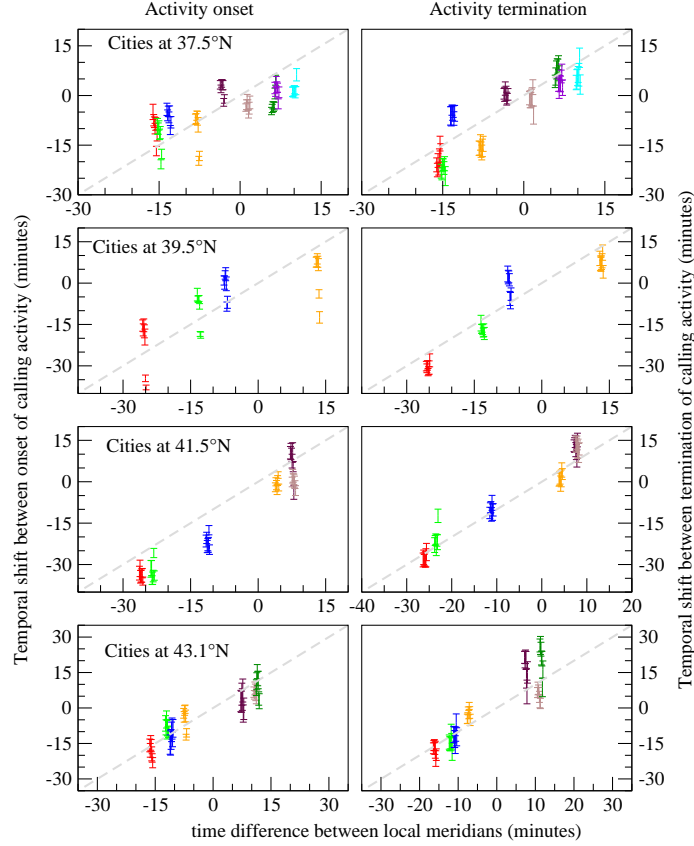


FIG. 3. **Time progression of the onset and termination of the calling activity along the geographical longitude.** The time shift $n^*\Delta$ that minimizes the divergence between the probability distribution of the first call P_F in a reference city and the corresponding distributions of the other different cities lying at the same latitude. 4 different bands are analyzed, centred at 37.5°N , 39.5°N , 41.5° , and 43.1° . For each city inside each band, the time shifts $n^*\Delta$ for the 7 days of the week are shown, as the set of 7 points with the same color located at the corresponding time difference between the local meridians of each city and that of the reference. The dashed line represents the time shift between the sun transit time at the reference city and a hypothetical point located at each corresponding longitude. The error bars represent the standard deviation from the average value for each day of the week. From the plot it can be seen that, for cities lying further away from the reference city, a bigger time shift is required to collapse the distributions.

the meridian of the city. This observation raises the question as to what external daily event induces such a synchronization. As the delays correspond to the time period between the local sun transit times of the cities, it seems plausible to think that the sun functions as a pacemaker for this entrainment.

At the latitudes where the studied cities are located, the time difference between the sunset in the summer and in the winter is around 3 hours, if the daylight saving is not taken into account, and the same holds for the time difference between sunrises. In contrast, the time difference between the mean time for the last calls between summer and winter is at most one hour [15]. However, there

is a clear synchronization between the sun transit time and the timings of the calling activity. This means that there should be an external clock functioning as a pacemaker. On the other hand, from a biological perspective, the time when the secretion of melatonin reaches its maximum coincides with the middle time between the sunset and the sunrise (solar midnight), once the night is as dark as possible. It has been proposed that the midsleep time coincides with the time for humans to have maximum melatonin secretion, and if the solar midnight shifts along the year, the time for the maximum melatonin secretion should follow a similar dynamics, as well as the entrained midsleep time.

If the midsleep time shifts in response to seasons, the timings of the calling activity should be influenced by its variation, in such a way that, if the time when humans are at the middle of their sleep happens at later hours, the timings of the calling activity next days would also occur at later hours. In another season, when the midsleep time happens earlier then the activity timings would also be shifted towards early hours. If this is the case, then the solar midnight would be functioning as the pacemaker, with which the calling activity timings are entrained.

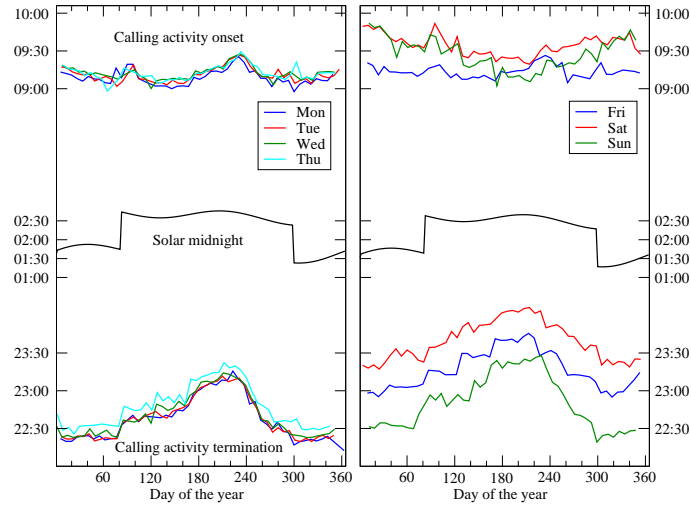


FIG. 4. **The yearly evolution of the time of the first call and that of the last call compared against the yearly shift of the solar midnight.** (Top sets) \bar{t}_F – average of the mean time of the first call of 3 sets of cities located at latitudinal bands centred at $\phi = 37^\circ 30'N$ (blue), $40^\circ 20'N$ (green), and $43^\circ 0'N$ (red). (bottom sets) \bar{t}_L – average of the mean time of the last call for the same sets of cities. In the middle of the panels, the solar midnight time in one of the cities within the band. The shape of \bar{t}_L^ϕ resembles to some extent the curve of the solar midnight, coinciding with the two minima (for days 130 and 302) and one of the maxima (for day 210). For the case of \bar{t}_F^ϕ , the curve shows some correspondence with the sunrise although to a lesser extent. The discontinuities introduced by the daylight saving shows in the curves, suggesting that the period of low calling activity is not solely influenced by the socially-driven time, but is synchronized with an external (astronomical) event. The number of cities inside the bands $\phi = 37^\circ 30'N$ (blue), $40^\circ 20'N$ (green), and $43^\circ 0'N$ (red), are 7, 6, and 8, respectively.

In order to find if there is any synchronization between these timings, we calculate the average of the mean time of the last call and that of the first call for 10 cities lying in the latitudinal band $37^\circ 30'N \pm 30'$ (see details in Methods), and compare that with the yearly evolution of the solar midnight in a reference city within this latitudinal band, see Fig. 4. It can be seen that only \bar{t}_L^ϕ

resembles to some extent the dynamics of the solar midnight, with their two minima and at least one of their maxima occurring around the same days of those of the solar midnight, although the relative amplitudes are not in correspondence. Moreover, the discontinuities introduced by the daylight saving is visible in all the curves, suggesting that the timings of the calling activity are not solely influenced by the socially-driven time, and are synchronized with external (astronomical) clock.

Age and gender dependence of the mid-sleep times

The period of low calling activity is bounded by the mean times for the last call during the night and for the first call in the morning. The width of this period changes across seasons [15] and is strongly influenced by the length of the day (or conversely by the length of the night) due to suppression of melatonin production. The midpoint of this low calling activity interval should correspond to the average time of human low activity, i.e. when the majority of the urban population is sleeping. In chronobiology studies, the midsleep time, corresponding to the time when human sleep is in the middle of its cycle, has been found [19] to vary with the age and gender of the individuals. Despite the fact that each individual's sleep-wake cycle is quite specific, with a chronotype ranging from early individuals (larks) to late (owls) [20], at the population level, a characteristic midsleep time can be consistently calculated, taken simply as the average of individuals' midsleep times.

From the mean times for the last call of the day, t_L and for the first call t_F of the next day, we define the period of low calling activity T_{LCA} as the elapsed time between t_L and t_F , as a measure of the time when cities cease their activity. In Fig. 5a, the width of the low activity period T_{LCA} of the most populated city in the dataset is shown, for 4 different days of a week (Tuesdays, and Fridays to Sundays), as a function of the subscribers' age and gender. There is a strong change of about 3 hours, moving from the age cohort of 20 to that of 40 year old. After that rather abrupt increase especially for Fridays and Saturdays T_{LCA} slightly decreases, reaching a local minimum value for the age cohort of 50 year old, and then it increases again to reach the highest value at the age of 78 years. For a common weekday (Tuesday) and Sunday, T_{LCA} increases almost monotonically with the cohort age, showing a small plateau for age cohorts between 45 and 58.

We have also tracked the midpoint of the inactive period, defined as the mid-time between t_L and t_F . Due to its similarity with the average time in the middle of the sleeping period [19], we name this minimum calling activity time as the mid-sleep time t_{mid} , calculated simply as $t_{mid} = (t_L + t_F - 24)/2$. Both quantities depend on the age and gender of each cohort, as can be seen in Fig. 5b. We find that, for women, t_{mid} happens at a later time. Also, there is a strong dependence on age, with younger age cohorts (20–30 year old) having late t_{mid} , i.e. around 30 minutes after the oldest age cohort (70–80 year old). This observation is in accordance with the observation of chronotypes [19], attributed to biological factor or internal clock being regulated by neuronal and hormonal mechanisms. In addition, we find a strange but consistent rise of t_{mid} for age cohorts of 45–65 year old, which we believe to be of social origin. Hence it seems that both biological and social factors play a role in changing t_{mid} , i.e. shifting the period of low activity to later hours.

In addition we find a clear difference between different days of the week, with the later times appearing for Friday and Saturday nights and the following mornings, and earlier times for Monday to Tuesday nights and following mornings (practically without any difference between them). The day of the week with the latest t_{mid} for different age cohorts varies such on Fridays and weekdays, 20–25 years old cohort has the latest t_{mid} , while for Saturdays, the 30–45 years old cohort shows the latest value. The results of T_{LCA} and t_{mid} for the most populated city are also and consistently

found in the next 5 most populated cities, as shown in the Supplementary Information (Figs. 6 and 7 respectively).

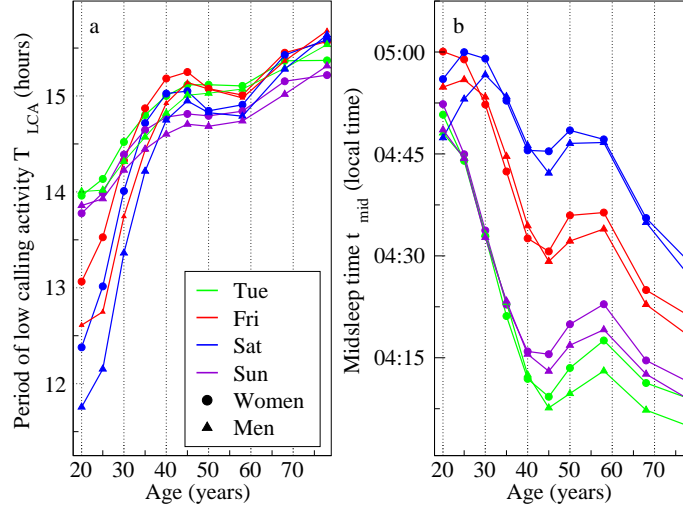


FIG. 5. **Period of low calling activity and midsleep times for different age and gender cohorts** (a) Period of low calling activity T_{LCA} . The T_{LCA} is calculated as the elapsed time between the mean time for the last call and that for the first call, as a function of the age and gender of different cohorts, for the most populated city in the dataset in 2007. (b) Midsleep time t_{mid} . t_{mid} is calculated as the time in the middle of the interval between the mean time for the last call and that for the first call, as a function of the age and gender of different cohorts of the same city. For each age cohort, T_{LCA} and t_{mid} are calculated for females (circles) and males (triangles) separately. Both quantities are different for different days of the week, and the corresponding plots are shown for (green) Tuesdays, (red) Fridays, (blue) Saturdays, and (violet) Sundays. As Mondays to Thursdays have similar values, therefore only the data for Tuesdays is shown.

CONCLUSION

In this study, we have found that the onset and termination of the period of low calling activity for people in cities at about the same latitude but at different longitudes are shifted according to their relative longitudinal separations. Cities westward from the easternmost analyzed city stop their activity later following the time delay of the sun transit time. This result suggests that a solar event acts as a pacemaker for the circadian rhythm of the period of low calling activity with the SWC bounded inside. In addition, we have found that the variations of the onset and the center of the period of low calling activity resemble the yearly variation of the solar midnight (or solar noon). However, when the behaviour of the period of low calling activity is compared with other characteristic solar events like the sunrise and sunset it appears to have different functional forms with different number and dates of maxima and minima. In this regard further research is needed though it seems that the solar midnight (or solar noon) acts as the exogenous clock that synchronizes both the onset and the center of the period of the low calling activity.

At the individual level, the knowledge of the midsleep time allows the determination of his or

her chronotype. However, using the distributions at the population level, we could determine the variation in the sleep duration and midsleep time as a function of age. Overall trends are in line with the earlier findings [19] and reveal an increase in the sleep duration and decline in the midsleep time with age. Several other intricacies are also evidenced at closer inspection. Firstly, the aspect of ‘social jetlag’ [21], defined as the difference between the midsleep times on free days and that of work days, becomes apparent across all age groups. Interestingly, although social jetlag is expected to give rise to extended sleep duration on free days as a compensatory effect, for young adults (20–25) we find that the sleeping periods are comparatively less on free days (Friday and Saturday nights and following mornings). Therefore, sleep deprivation is likely to be maximum for this age range. Second, previous observations suggest a monotonic decrease in the midsleep time from around 20 years of age individuals, which is attributed to endocrine factors [19]. In contrast, we observe a reversal in trend at the age of 45 years when the midsleep time rises till 55 years of age before starting to decrease again. We argue that the overall pattern is a superposition of biological factors and factors that arise from the social environment of the individuals. The decrease occurring post 20’s coincides with the reproductively active period spanning 25–35 year old individuals when they are involved in parental care of their young children and thus can be expected to synchronize their sleeping habits with that of the latter. As the offspring become adolescent, the parenting demands are less or assume different forms, and for the parents aged 40 and above, their sleeping hours get dissociated from that of their children. The age cohort of 50–60 year old is typically that in which the children themselves marry and begin to reproduce in their turn. The calling activity persisting from later hours of the evening into the night would represent parents maintaining regular interaction with their adult children.

MATERIALS AND METHODS

In this study, we have analyzed the very large dataset of anonymized call detail records (CDRs) from a mobile phone provider offering services in a European country. Note that the anonymization was performed by the service provider prior been given to us. The dataset contains CDRs of around 10 million subscribers of the provider during 2007, such that more than 3 billion calls between 50 million unique identifiers are included. Each record contains the date, time, duration, and anonymized caller and callee identifiers. The dataset also includes demographic information of the majority of the subscribers, and for those cases, the age, gender, postal code, and location of the most accessed cell tower (MACT) are known. There are three possible locations associated to each user, namely the associated city center, the location of the MACT and the center of the postal code region, and we use them to define if the subscriber “lives in a city” when their three associated locations are sufficiently close to each others (a more detailed description can be found in [15]). In this study, we chose 36 of the cities with more than hundred thousand inhabitants in 2007, in such a way that our final analysis takes into account the calling patterns of around 1 million subscribers in total. Locations of the subscribers are associated with the locations of the cities they reside. Each city is associated with the following two geographical coordinates: the latitudinal coordinate is fixed as the midpoint of a latitudinal band including the city, and the longitudinal coordinate, defined as the angular distance between the city and a reference point located in the studied region.

In Fig. 1, we show $P_{all}(t, d)$ (green curve) during the days $d=214 - 215$ (marking early August) for a city of more than half a million inhabitants. The probability distribution $P_{all}(t, d)$ has two high activity peaks with the first corresponding to the morning calls, peaking around noon, and the second related to the evening calls, peaking around 8:00 pm. For every day throughout the year and for all the cities included in this, study this bimodal pattern is present. The high activity

peaks are delimited by two periods of low activity, first one centered around 4:00 pm related to the time after lunch, and the second one in the middle of the night, around 4:00 am lying inside the sleeping period.

To study the specific times when the calling activity rises and falls, we analyse separately the ‘morning’ and ‘night’ periods, defining the former between 5:00 am and 3:59 pm, and latter between 5:00 pm and 3:59 am on the following calendar day, in such a way that each one is 11 hours long. During each ‘morning’ we select only the first call made by each user inside that period and construct the associated probability distribution for the time of the first call $P_F(t, d)$, directly related to the rise of calling activity. Similarly, during the ‘night’ we define the corresponding probability distribution for the time of the last call $P_L(t, d)$ by taking into account only the last call made by each user within that period. In Fig. 1, it can be seen that the three defined probability distributions $P_{all}(t, d)$, $P_L(t, d)$ and $P_F(t, d)$ for consecutive days during winter, for a particular city with a population over a half a million. The shape of the distributions $P_L(t, d)$, $P_L(t, d)$, and $P_F(t, d)$ depicted in Fig. 1 for a specific day appear to be preserved for all the days and cities we have studied.

Quantifying delays between calling activity timings

In order to quantify the actual time shift between the distributions P_L last calls for cities lying along different Longitudes, we proceed as follows. First, for all the cities within the band, we calculate all the distributions $P_L(t, d)$ between January 2nd and December 31st. For each day d , we fix $P_L(t, d)_{0^\circ}$ of the city labelled ‘0°’ as the reference distribution, and for every other city c in the band, we compared the reference $P_L(t, d)_{0^\circ}$ with a shifted versions of $P_L(t + n\Delta, d)_c$ distribution, with $-5 \leq n \leq 8$ and $\Delta = 5$ min, to find the time shift $n^*\Delta$ that minimizes the divergence D_{KL} between them. Here, D_{KL} is the Kullback-Leibler divergence measure, defined as $D_{KL}(P, Q) = \sum_i P_i \log(P_i/Q_i)$, with P, Q being the two discrete distributions. Once we find the set of n^* for each city across the year, we calculate their average $\langle n^*\Delta \rangle$, and plot them in the right column of Fig. 3. As the time for the mean time of the last call is different for different days of the week [15], the average is calculated separately for each day of the week. We apply the same procedure for the first call distributions P_F , and the results are shown in the left column of Fig. 3.

Averaging the mean times of the calling activity inside a latitudinal band

In order to find if there is any relation between t_L and t_F and the solar midnight, we have chosen 10 cities, lying in the latitudinal band around $37^\circ 30'N \pm 30'$. For each city, we shift its corresponding distributions in accordance with its longitudinal difference to collapse them into one. Then we calculate the average mean time of the last call, $\bar{t}_L(d) = \langle \bar{t}'_L(d, c) \rangle$, where, $\bar{t}'_L(d, c)$ denotes the mean time of the last call for the shifted distribution for a city c belonging to the band during the day d , and $\langle \cdot \rangle$ denotes the average over all cities lying within the band. Similarly, we calculate the average mean time for the first call $\bar{t}_F(d)$ for the given latitudinal band. The quantities $\bar{t}_L(d)$ and $\bar{t}_F(d)$ are compared with the time at which the solar midnight occurs in the reference city of the band. I should be noted that in the original curves there are days of national holidays and local festivities that introduce drastic pattern changes, which we filter out to construct the final curves.

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COMPETING INTERESTS

The authors declare that they have no competing interests

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SUPPORTING INFORMATION

S1 Fig. **Age and gender dependence of the period of low calling activity and of the mid-sleep times.** The behaviour of T_{LCA} and t_{mid} as a function of age and gender is calculated for the most populated city in the dataset, and the result are shown in Fig. 5 of the main text. In addition we have calculate the corresponding quantities for the next 5 most populated cities, ranging from around 500000 to 1600000 inhabitants in 2007. For each city, the shapes of T_{LCA} and t_{mid} are similar to those presented in the main text, showing that the behaviour is a general trait of the people living in urban areas and not a particularity of a specific city, as can be seen in Figs. 6 and 7.

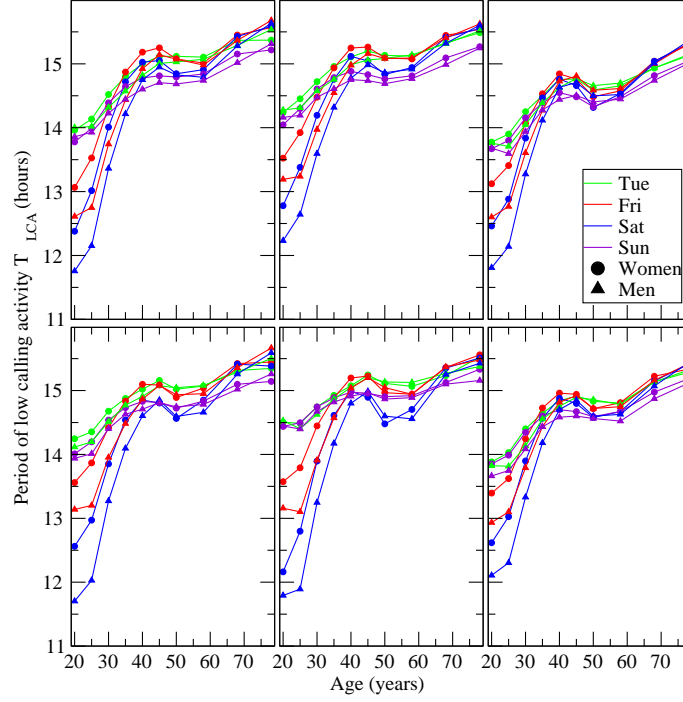


FIG. 6. **Period of low calling activity T_{LCA} for different age and gender cohorts.** The T_{LCA} is calculated as the elapsed time between the mean time for the last call and for the first call, as a function of the age and gender of different cohorts, for the six most populated city in the dataset in 2007. For each age cohort, T_{LCA} is calculated for females (circles) and males (triangles) separately. T_{LCA} is different for different days of the week, and the corresponding plots are shown for (green) Tuesdays, (red) Fridays, (blue) Saturdays, and (violet) Sundays. Mondays to Thursdays have similar values, therefore only the data for Tuesdays is shown.

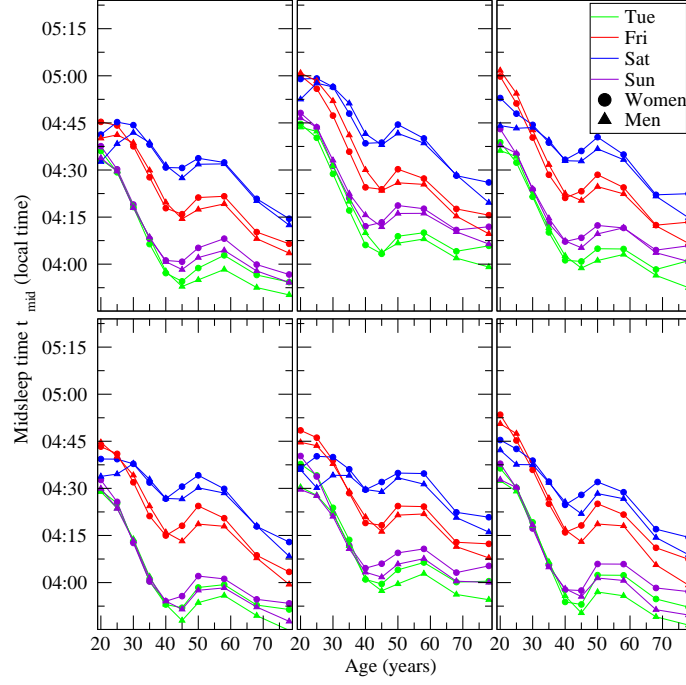


FIG. 7. **Midsleep time t_{mid} for different age and gender cohorts.** t_{mid} is calculated as the time at middle of the interval between the mean time for the last call and for the first call, as a function of the age and gender of different cohorts, for the six most populated cities in the dataset in 2007. For each age cohort, t_{mid} is calculated for females (circles) and males (triangles) separately. t_{mid} is different for different days of the week, and the corresponding plots are shown for (green) Tuesdays, (red) Fridays, (blue) Saturdays, and (violet) Sundays. Mondays to Thursdays have similar values, therefore only the data for Tuesdays is shown.